VEPP-4M OPERATION IN THE LOW-ENERGY RANGE

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Abstract

The possibility of effective operation of the modified e^+e^- collider VEPP-4M with the new detector KEDR in the low-energy range of 1-1.8 GeV is discussed. This energy range is unusual for the facility but it is of interest for measuring the total cross section of the e^+e^- annihilation into hadrons and studying the J/ψ physics. We plan to perform in the nearest future an experiment on the high precision measurement of the τ-lepton mass in the vicinity of the threshold of its production (1.78 GeV), using the method of the resonance depolarization. Preliminary experimental data on the luminosity optimization at low energies are given and analyzed. The most important for VEPP-4M problems related with luminosity, such as the single-beam effect of vertical oscillations self-excitation depending on the beam current and length, non-linear beam dynamics, application of two dipole wiggler magnets of a 1.8 T field for raising the peak luminosity due to the beam "blow-up" and increase in radiation damping decrements are under consideration.

1 INTRODUCTION

VEPP-4M [1] is a modernized VEPP-4 collider that was in successful operation in 1980-1985. Main goals of the modernization beside installation and commissioning of the new KEDR detector [2], include:

- Development of the tagging system for scattered electrons and positrons that based on the magnetic spectrometer and provides precise determination of the $\gamma\gamma$-invariant mass.
- Modification of the final focus quadrupoles to reach $\beta_y^* = 5$ cm.
- Design, production and commissioning of two insertions in the middle of the collider arcs with additional set of vertical separators for 2×2 -bunches operation.

The maximum designed energy of VEPP-4M is of 6 GeV and its circumference is equal to 366 m. Basically, this facility was intended to study physics of ϒ - meson and two-photon processes. However, because of the strong interest in J/ψ and ψ´physics in recent years, it was proposed firstly to concentrate the facility efforts in the low energy range of E = 1.5 – 1.8 GeV

The low energy region is not typical for VEPP-4M and special beam studies are required to investigate the beam behavior and obtain maximum available luminosity. Just that purpose was emphasized during two machine runs in 1996-1998 and 2000-till today. A shutdown in between was mainly due to the KEDR assembling completion and VEPP-4M lattice modification. Several runs of the collider with the detector for scanning the J/ψ -energy range were dedicated to system testing both at KEDR and VEPP-4M.

The results obtained overview of problems and discussion of the ways of their curing are presented in the paper.

2 LOW ENERGY LUMINOSITY

2.1 Collective effects

Due to the low radiation damping rates ($1/\tau \sim 10$ s^{-1}) different collective effects even in the single bunch operation mode are pronounced. A dominant longitudinal instability is caused by a rather large longitudinal impedance ($Re(Z_{\|}) \approx 4$ kOhm) of vacuum chamber and parasitic HOM of the five old-type accelerator cavities (f_0 = 181 MHz). Since at the low energy we need 2 cavities only, the rest 3 were tuned down for Δf = 12 kHz (that is equal approximately to the synchrotron frequency) to introduce artificial damping of the dipole oscillation mode with the rate that exceeds the radiation one by a factor of 100.

For the 2×2-bunches mode we are planning to install two active third-harmonic cavities to control the synchrotron oscillation frequency for each bunch independently.

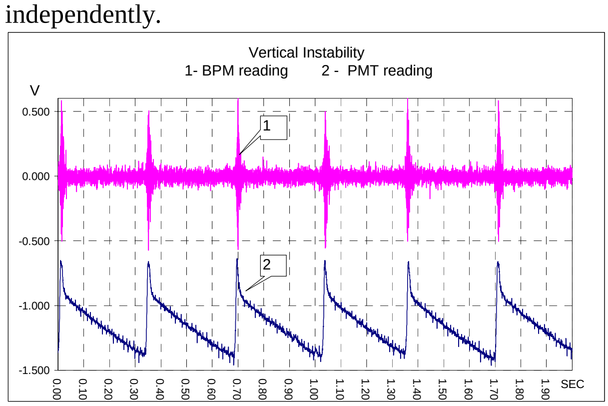

Fig.2.1.1 Observed signal of the vertical instability.

In a transverse plane, a notable beam instability associate with a low frequency vertical oscillation at a bunch current about 2 mA, which provides a significant vertical beam size increasing and reduces the luminosity. This effect (Fig.2.1.1) looks like the so-called “saw-tooth” instability and acts equally to both e^+e^- beams. Despite the origin of this instability is still unclear we can cure it by increasing twice the radiation damping with the help of dipole wigglers. Further investigation of this effect is under way.

2.1 Beam-beam performance

Previously the VEPP-4 peak luminosity was about 5×10^{30} $cm^{-2}s^{-1}$ at E =5 GeV. Now for the same energy of VEPP-4M we hope to reach 2×10^{31} $cm^{-2}s^{-1}$ with the existing optics and 10^{32} $cm^{-2}s^{-1}$ with two superconducting wigglers and β^* reduced down to 2.5 cm.

At low energy the luminosity reduces drastically ($\propto E^4$) and different problems arise due to the low damping rates. To improve the luminosity performance we use a pair of normal-conducting wigglers with the peak field H = 1.8 T, which allows one to increase the horizontal emittance by a factor of 4 at 1.5 GeV. A numerical simulation of the beam-beam interaction with the LIFETRACK code [3] shows that with the help of the wigglers we can reach the luminosity L ≈ 10^{30} $cm^{-2}s^{-1}$ at the 1×1 mode for 1.5 GeV. Fig.2.2.1 demonstrates the luminosity improvement due to the wigglers excitation.

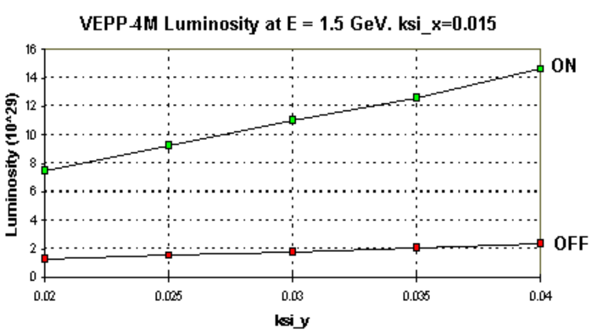

Fig.2.2.1 VEPP-4M luminosity with- and without the dipole wigglers.

Table 2.2.1: VEPP-4M luminosity (LIFETRACK) (ξ_x = 0.015, ξ_y = 0.03)

Wigglers	Current (mA)	L_{max} ($cm^{-2}s^{-1}$)
Off	1	1.8×10^{29}
On	5	1.1×10^{30}

Table 2.2.1 lists the simulation results while the experimental ones are shown in Table 2.2.2.

The experimental data with the switching-on wigglers correspond to ξ_y = 0.046 and the beam lifetime τ = 1.3 hour. During this run we have found that the maximum possible emittance increasing (4 times) by the wigglers is not the optimal one from the viewpoint of highest luminosity and optimization of the wiggler parameters will be continued. The reason as it seems now is the dynamic aperture limitation.

Table 2.2.2: VEPP-4M luminosity (experiment)

Wigglers	Current (mA)	L_{max} ($cm^{-2}s^{-1}$)
Off	1.5	1.6×10^{29}
On	3.2	0.7×10^{30}

2.3 VEPP-4M non-linear beam dynamics

The horizontal beam size and energy spread increased by the wigglers can cause the current loss if the dynamic aperture (DA) is rather small. A single beam non-linear motion for VEPP-4M is driven by strong chromatic sextupoles. It is known that there are two main mechanisms of the short-term DA limitation for the sextupole-driven electron machines. If the tune point is chosen in the vicinity of the strong sextupole resonance, the DA is determined by the resonance fixed points. Otherwise, small high-order resonances provide particle diffusion through the overlapped stochastic layers. The latter is true for the VEPP-4M tune point that situates slightly above the half-integer resonance (both for horizontal and vertical motion). The numeric simulation results (Fig.2.3.1) show high order resonance islands and the stochastic particle motion.

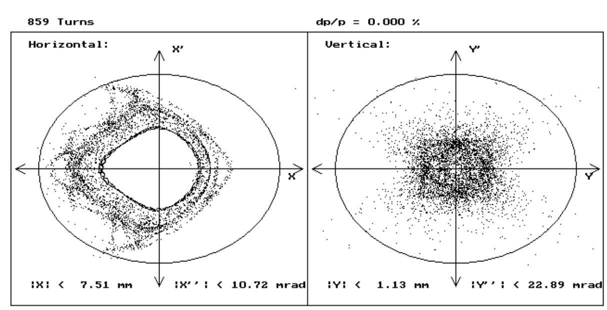

Fig.2.3.1 VEPP-4M phase-space plot.

Non-linear beam dynamics experiments have been performed at VEPP-4M to measure phase space trajectories, dynamic aperture and non-linear tune shift. Experimental set up comprises the single-turn BPM, horizontal and vertical kickers and movable scrapers.

The measurement of the detuning coefficients defined as

$$\Delta Q_x = C_{xx} J_x + C_{xy} J_y , \quad \Delta Q_y = C_{xy} J_x + C_{yy} J_y ,$$

where J_{ij} is the action variable yields C_{xx} = 1.4 mm^{-1}, C_{xy} = -1.0 mm^{-1} and C_{yy} = -5.2 mm^{-1}. These values are approximately twice as large as those predicted by model simulation, and further investigation of the additional non-linearity sources is necessary. A comparison of the measured and estimated dynamic aperture also shows a discrepancy with a factor of two. However, insertion the measured values of the detuning coefficients in the model estimation significantly reduces the difference between measurement and prediction (Fig.2.3.2).

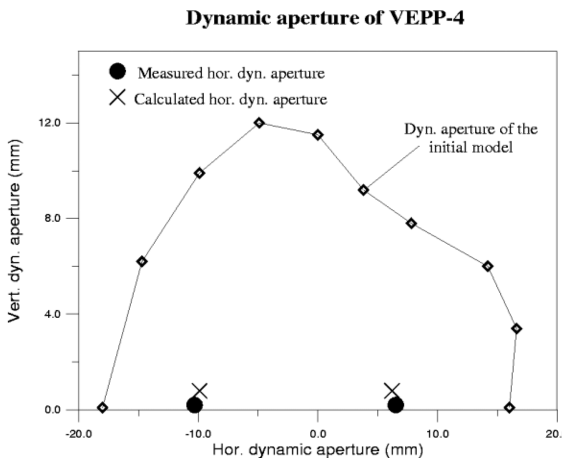

Fig.2.3.2 VEPP-4M dynamic aperture. Line – the initial model, dots – the measurement, crosses – the model with the measured detuning coefficients.

Two ways of the DA improving were checked experimentally:

- Re-distribution of the chromatic sextupoles in order to reduce the main resonances driving terms allows increasing the DA by a factor of 1.5.
- Controlling the detuning coefficients with the help of octupole magnets. In spite of good simulation results this method fails in the DA opening and further experiments are being planned.

3 PRECISE ENERGY MEASUREMENT

To measure the J/ψ resonance and τ lepton mass, a precise calibration of the beam energy is highly desired. We are planning to do that using the electrons prepolarized in VEPP-3 (E = 2 GeV, $\tau_P \approx$ 30 min). Depolarization of the beam in VEPP-4M with the low amplitude RF-kicker allows one to measure the spin precession frequency (through the intrabeam scattering count rate reading) and hence the beam energy [4]. The VEPP-4M depolarization time is rather large (≈100 hours), so we expect an effective suppresion of the spin diffusion due to the quantum fluctuation, magnet field ripple, etc. The registration system includes two pairs of scintillator counters, which can be moved precisely inside the vacuum chamber. According to estimation, the relative error of the energy will be about 3×10^{-5} with the polarization level of ~80%. All elements of the system are designed and its manufacturing is in progress. First experiments are expected in June-July, 2001.

Additionally we consider a different possible scheme for the accurate on-line beam energy measuring. The method, previously demonstrated at BESSY-I [5], based on the CO_2 laser photons (ε = 0.12 eV) back scattered against the VEPP-4M e^+e^- beams. To detect the back scattered γ-rays we are planning to use the 500 mm^3 HPGe detector that can be calibrated precisely in the ~1-3 keV region by a radioactive isotope. Calculation shows that to have the scattered photons in the energy range of 1-3 keV, which is convenient for registration, we need to modify the BESSY-I scheme and insert a laser cavity into the storage ring vacuum chamber at the angle of ~80° to the beam axis.

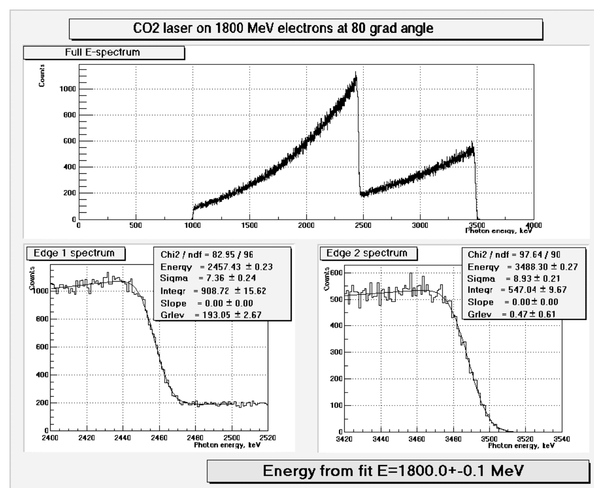

Fig.3.1 Precise energy measurement with the Compton back-scattering.

Fig.3.1 shows the simulation results for the 100 W CO_2 laser and 1000 s measuring time. According to the simulation, the relative energy error can be as small as $5\div6\times10^{-5}$.

4 KEDR STATUS

KEDR is a general-purpose detector with a 1 T solenoid magnetic field for experiments at VEPP-4M in the energy range of 2E = 2 ÷ 12 GeV. Now all the systems of KEDR (including the vertex detector, drift chamber, aerogel Cherenkov counters, LKr calorimeter, superconducting coils, etc.) are assembled and commissioned. In a test run the magnetic field reached a 0.7 T level that is quite enough to get the optimal resolution at the VEPP-4M low energy mode. During this run, the influence of the longitudinal field on the

VEPP-4M beam behaviour was studied and different schemes for the betatron coupling compensation were considered.

To check the KEDR acquisition systems a test scanning of the J/Ψ meson was performed.

Detector KEDR is equipped with the tagging system, which provides registration of the scattered electrons and positrons in the γγ experiments. In situ calibration of the tagging system is available with the laser photon backward Compton scattering. The tagging range for γ-quanta is 2÷61 % of the e^+e^- beam energy with the energy resolution about 1÷3 % of the γ-quantum energy in the whole tagging range.

5 PROBLEMS AND FUTURE PLANS

At present one of the main problems of the VEPP-4M facility is the low efficiency of the positron injection in the cascade injection scheme: linac (e^-, 50 MeV) → converter (e^+, 8 MeV) → synchrotron (350 MeV) → VEPP-3 (up to 2 GeV) → VEPP-4M. To overcome this disadvantage a new injection facility at BINP now is underway. It will consist of two linacs in series (300 MeV for e^- and 510 MeV for e^+e^-) and a 510 MeV damping ring. A planning efficiency of this facility is around 2×10^{10} e^+e^-/second.

To inject the beam in the VEPP-4M vacuum chamber, a 2.5 GeV booster synchrotron is now under consideration. Main parameters of the synchrotron are given in Table 5.1.

Table 5.1 Main parameters of the VEPP-4M booster synchrotron.

Injection energy	0.51 GeV
Extraction energy	2.5 GeV
Beam current	200 mA
Circumference	132 m
Repetition rate	1 Hz
Horizontal emittance	78 nm
Dipoles No	28
Quads No	40
Sextupoles No	16

The booster synchrotron is of the usual racetrack type with 12 FODO cells per arc and two 3-m-long dispersion-free straight sections to accommodate two RF cavities and injection/extraction equipment. It is planned now to accelerate a 200 mA maximum current in 50 bunches.

5 ACKNOWLEDGMENT

This article is a brief review of the work done by many dedicated people at the BINP VEPP-4M facility. Many special thanks to V.Kiselev, S.Nikitin, N.Muchnoi, V.Blinov.

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